

Distributed Autonomous Sensing

Micro/Nano Transduction in

Miniaturized Chemical/Biological Sensing

Dr. James S. Murday

Head, Chemistry Division, Naval Research Laboratory

Surface Acoustic Wave (SAW) Chemical Microsensors

from R&D to the Joint Chemical Agent Detector (JCAD)

Sensor Uses SAW Technology to Detect Chemical Vapors

1981 85

- SAW microsensor developed at the Naval Research Laboratory (NRL)

1984 92

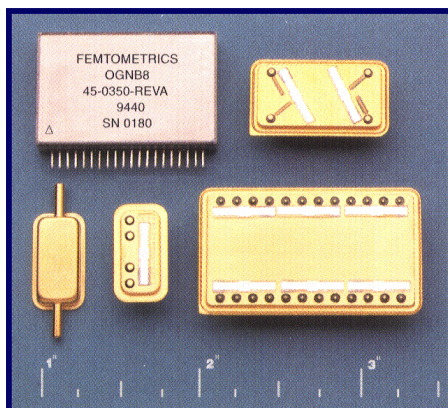
- SAW hardware developed at Microsensors, Inc.
- Chemically selective coatings developed at NRL
- First 4- sensor array & preconcentrator developed at NRL
- Pattern recognition used to interpret results

1993 95

- SAW hardware developed at Femtometrics, Inc.
- SAW sensors field deployed in Korea

1996 Present

- SAW microsensor flies on UAV
- JCAD program begins



JCAD - Joint Chemical Agent Detector

- Provide users with the capability to automatically detect, identify, quantify, localize, and provide warning of the presence of Chemical Warfare (CW) agent vapors by agent class.
- Provide commanders information on the type, level, and extent of CW contamination and total CW agent dosage received.

JCAD Engineering & Manufacturing Development

Human Systems Program Office, Brooks AFB, TX

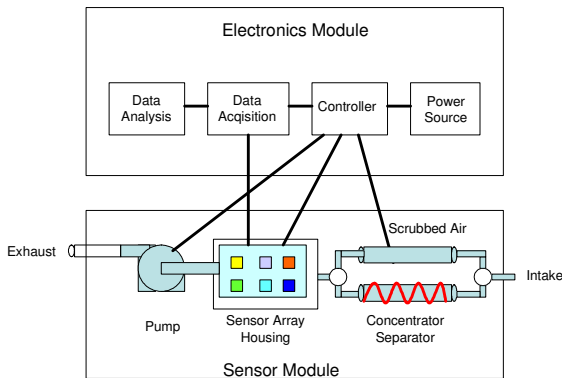
- Phase I (Feb 98 M02):
 - Engineering Development
 - Design Test & Evaluation
- Phase II (Apr 02 M03):
 - Final Form Factor
 - Production Qualification Tests
- Production Contract Award in FY04 (250,000 units)

POC: *Dr. Susan Rose-Pehrsson*
Code 6112; 202-767-3138

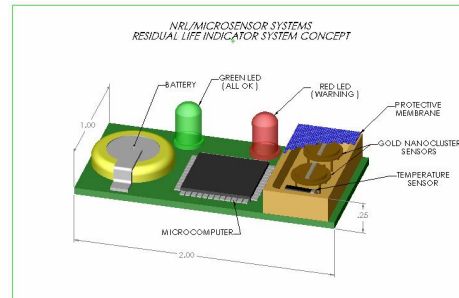


Hybrid Silicon Chip Integrated MIME CW Agent Detection System

Schematic Sensor System Diagram



Artist's Depiction of a
Micro Residual life indicator



Current Version (125 g/3x2x1")
"cigarette pack size"



Future Version (10g/1x1x0.5")
"wristwatch size"

Targeted Applications
UAV Platforms
Residual Life Indicators
Drop-off Sensors

Description of Effort:

- This proposal is a joint NRL-MSI effort to fabricate an integrated detector system as a silicon chip hybrid:
- Integration of gold cluster vapor sensitive materials and transduction mechanism with planar silicon technology
- Fabrication of sensor and supporting components (electronics, microprocessor, etc.) on separate silicon chips connected by vapor lines and pneumatics
- Design for minimal power consumption (mW)

Benefit to Warfighter/First-Responders:

- Small size, light weight and low power consumption of this detector system permit unobtrusive incorporation into a garment, helmet or on a UAV.

Challenges:

- Develop self-assembly chemistry for incorporation of gold cluster vapor responsive component into a silicon chip
- Reduce of supporting electronics and microprocessor functions to integrated silicon chip package
- Miniaturization/incorporation of vapor lines and pneumatics
- Integration/programmed electronic control of detector system

Maturity of Technology: Applied Research (6.2)

Business Area: Chemical Point Detector

NRL POC: Dr. Warren Schultz, 202-767-2479
Dr. Art Snow, 202-767-5341

Objective:

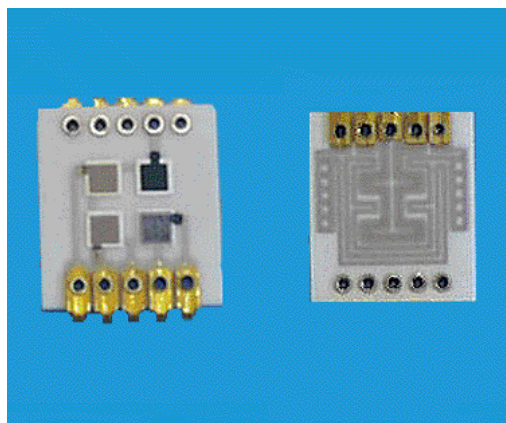
- Accelerate miniaturization of new gold cluster based toxic chemical vapor detection system from a printed circuit board configuration to a light weight/small volume hybrid silicon chip integrated package with an ultralow power requirement.

Description:

- An ensemble of nanometer scale gold clusters serves as a highly sensitive and selective solid-state element for adsorption of chemical species and transduction to an electronic signal.

Smart Microsensor Arrays for Hazardous Material Detection

The microsensor arrays provide fingerprinting of analytes. Cyclic voltammetry is used to generate the unique electrical signatures that are analyzed by multivariate signal processing.



Cermet Sensor

Description:

The program will develop, fabricate and test robust smart sensor arrays using cermet electrochemical sensors with associated readout electronics. The sensor arrays will sense a wide variety of chemical agents including blood agents and toxic industrial chemicals. Pattern recognition techniques will be used to determine the presence of chemical agents and toxic industrial chemicals. The resulting detection system provides means of detecting complex chemical system.

Objective:

Develop a smart microsensor array capable of detecting all the chemical agents, plus blood agents and toxic industrial chemicals

Payoff:

Single instrument capable of meeting the JCAD Performance Specification, document YAE-9701, section 3.2.2.2 Detection and Identification, dated 13 August 1999.

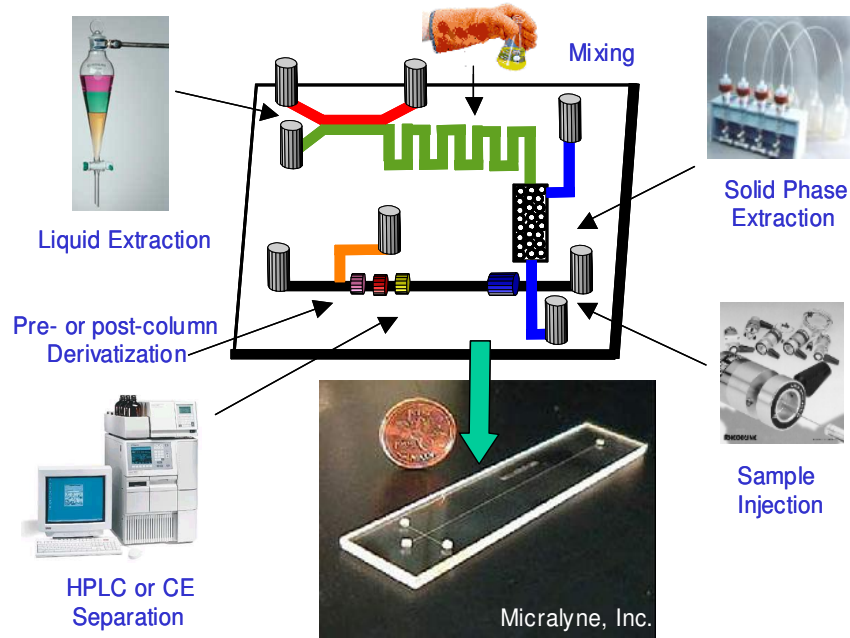
Deliverables:

- **Proof of Concept completed in FY02:** technology demonstrator was fabricated and tested. Data analysis methods demonstrated sensitivity and selectivity.
- Advanced prototype available in FY03
- Commercialization in 2-3 years

Principal Investigators:

- Dr. Susan Rose-Pehrsson, NRL 6116; 202-767-3138
- Dr. John Ziegler, General Atomics

Anti-Terrorism MicroChip Sensor



Objective:

- Develop multi-analyte, portable sensor for CWA, blood agents, organic and ionic explosives.

Payoff:

- Low ppb level detection capabilities;
- Selective, chromatographic separations in seconds;
- Simultaneous info on five different classes of terrorist analytes;
- Portable and low cost

Deliverables:

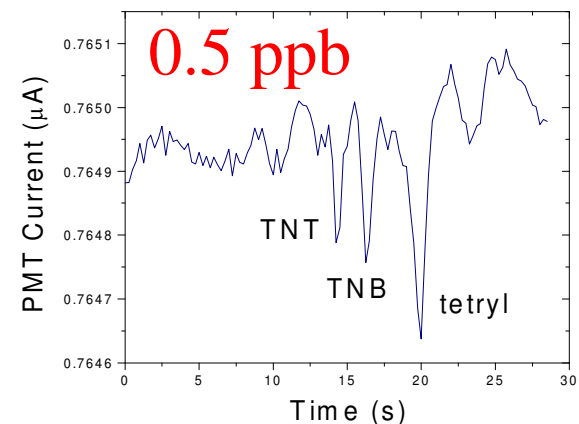
- Fieldable prototype available in FY04
- Advanced prototype (commercialization)- FY05

NRL POC: Dr. Warren Schultz, 202 767 2179

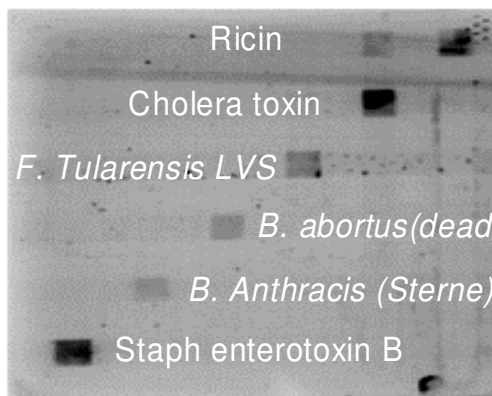
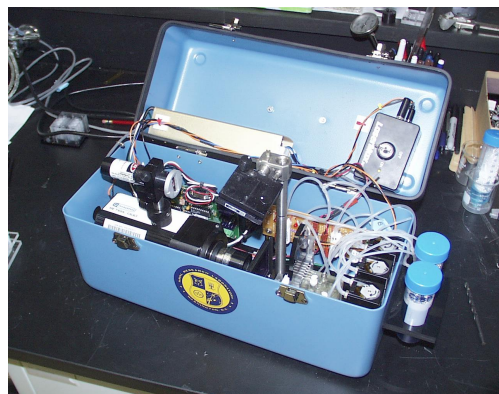
Dr. Greg Collins, 202-404-3337

Description:

- Multichannel capillary electrophoresis sensor;
- No mechanical pumps-solution transport achieved using high voltage application and system of switches;
- Separate microchannels on same microchip utilize characteristic reagents for each analyte class;
- Single sample injection analyzed simultaneously down five separate channels;
- Electrophoretic separation ensures selective response.



Array Biosensor



Description

NRL has developed an array biosensor for the rapid simultaneous analysis of multiple samples for multiple analytes. The biosensor has a patterned array of “capture” antibodies immobilized on the surface of a planar waveguide. A fluorescence assay is performed on the patterned surface, the loci of which are used to identify what analyte is present. Image analysis software determines the identity of the analyte and quantifies the fluorescent signals from each spot.

Features and advantages include:

- Sensitive: <500 pg/mL toxins & <1000 cfu/mL bacteria.
- Flexible: simultaneous detection of proteins, toxins, bacteria, and viruses
- Rapid: <10 minutes
- Parallel processing: simultaneous analysis of multiple samples for multiple analytes.
- Designed for on-site analysis: stable reagents, compact, lightweight, automated

Applications include:

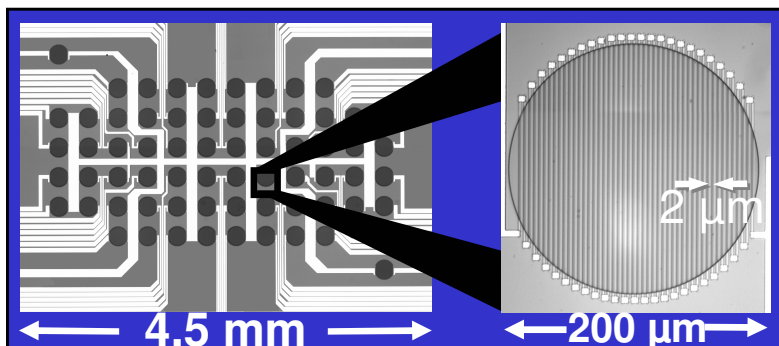
- Infectious disease diagnostics
- Biological warfare defense
- Food & beverage safety
- Agricultural/veterinary testing
- Environmental monitoring

Principal Investigators

- Dr. Fran Ligler, NRL 6908
- Dr. Chris Rowe Taitt, NRL 6910



Bead Array Counter (BARC)



64-sensor BARC chip &
next generation instrument



Next Generation
System

Concept:

- Uses DNA-based hybridization assay to detect & identify BW agents
- But uses a magnetic bead to label the hybridization reaction
- Bound magnetic beads detected with embedded magnetic sensor in the chip
- Plan to add immunoassay on same chip

Objective:

- Develop *optics-free* DNA chip biosensor with enough sensitivity to eliminate need for PCR amplification

Payoff:

- Combines state-of-the-art gene chip technology with NRL's MRAM (magnetoresistive memory) program
 - Current BARC sensitivity is ~1800 molecules
 - Current BARC chip has 64-sensing elements for multi-analyte detection

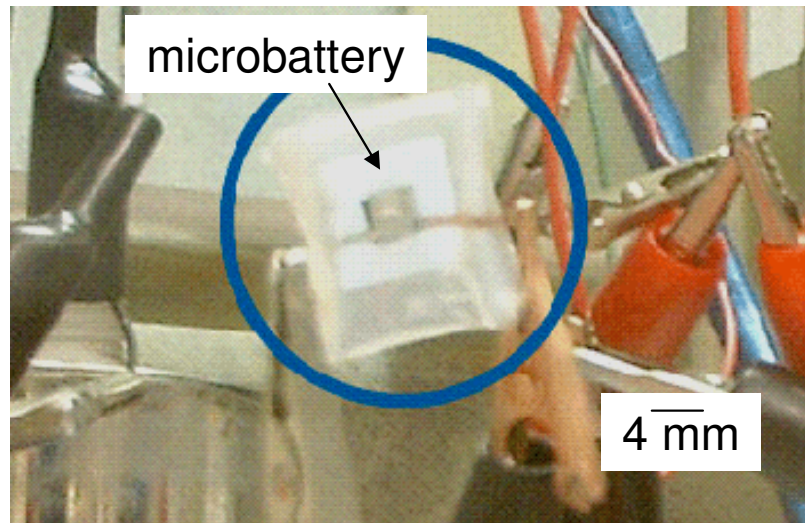
Deliverables:

- Advanced prototype (funded by TSWG) available in FY05
- Talks with commercial vendors ongoing

POC:

- Dr. Warren Schultz, NRL, 202-767-2479
- Dr. Lloyd Whitman, NRL, 202-404-8845

Laser Engineered Microbattery



ACCOMPLISHMENTS

- Developed protocols for fabricating components of Li-ion microbatteries
- **Operated first generation packaged Li-ion microbattery**
 - § 4.17 and 3 V
 - § 155 μAh capacity
 - § 1.5mg LiCO_2 (+) vs. Carbon (-)
 - § >150 hrs. in dry Argon
 - § >24 cycles in ambient air

NAVY/DOD PAYOFF

- New custom designed micro-power sources for microelectronic devices (e.g. distributed microsensors)

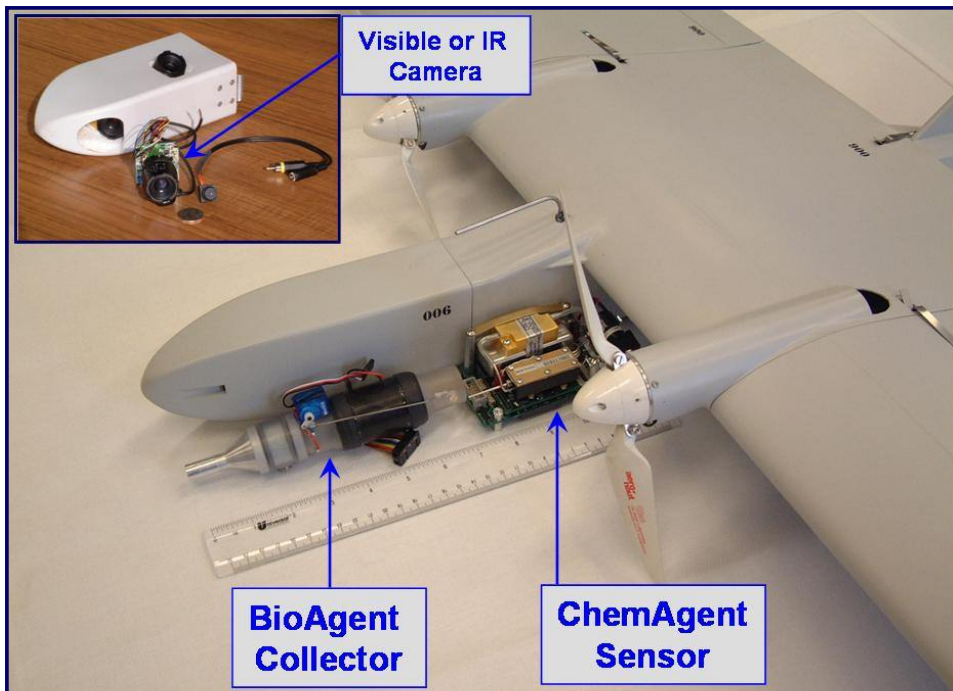
POC

- Dr. Karen Swider-Lyons, 202-404-3314

APPROACH

- Fabricate microbatteries from library of deposition methods including laser direct-write (DW) and laser micromachining
- Develop packaging to optimize battery performance with minimal addition of weight and size
- Create custom hybrid microphotovoltaic/microbattery power system
- Integrate microbatteries directly into microcircuits

Advanced Tactical Recce



Enabling Capabilities

- Man portable UAV with autonomous flight capability for small unit reconnaissance and threat detection.
- Real time Chemical Agent (CA) detection with data downlink.
 - Chemical sensor tested multiple times with simulants, **Live Agents** and interferents in both wind tunnel and surety rooms.
- Biological Agent (BA) collection and concentration.
 - PCR agent analysis completed on returned sample in 25 minutes with human sub infectious dose sensitivity.
 - Antibody based analysis for Botox and Ricin simulants demonstrated

Validation

- Validated at DOD's Gold Standard facility, APG, MD

Final System Includes

- Ground Control Station (GCS) to provide robust command and control and to receive downlink data.

POC

- Dr. Warren Schultz, NRL Code 6101, (202) 767 2479

Beyond Miniaturized Chem/Bio Sensing at NRL

Next step for development of distributed autonomous systems may be from integrated, deployment-oriented R&D

balancing:

- mobility (space, air, land, water, fixed),
- sensors,
- data fusion and communication, and
- **power** (creation, conservation, efficiency, integration)

to develop product systems with a range of capabilities

with system integration as a research activity.

Dr. Jill Dahlberg,
dahlburg@utopia.nrl.navy.mil

— **Naval Research Laboratory** —